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ELECTRONIC HEATING

By GEO. R. COOPER,
D.Sc., Ph.D., B.Sc. (Hons.), F.R.S.A.

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1. The first use of high frequency currents for heating steel and ferrous alloys by means of induction dates back to the early days of electricity. It is only within the last few years, however, that the electrostatic application of high frequencies has found employment in industry for the heating of materials within the insulating class. One of the first commercial process to which this method was applied was the heating of laminated wood, for the setting of the synthetic glue. It is now utilised on a large scale. This, incidentally, is a tribute to the adaptability of the system; for with wood, difficulties arise due to the variation of electrical properties, particularly the dielectric loss with change of moisture content. There are, of course, many other applications where the uniformity of heating provided by H.F. methods is an outstanding recommendation, and almost every week new applications are being developed.

Obviously the demand for industrial type H.F. generators will grow, and in the future it will not be adequate merely to provide the limited ratings of medical diathermy equipment adapted to industrial use. Higher ratings will be the trend in order to reduce process heating time to a minimum, and higher frequencies to obviate the use of excessively high voltages.

During the growth of radio and allied industries it was found that as higher frequencies were brought into use the standard insulating materials became less and less suitable, because they could not withstand the increased stresses and dissipated electrical energy in the form of heat. In fact, one of the earliest ways in which the effect of H.F. heating on moulding materials was realised was when complaints were made about the quality of materials, complaints which were overcome by introducing new materials of lower loss characteristics.

The heating of dielectric material by alternating current was therefore originally a nuisance, but with the enlarged scope of the science of electronics this very fault has been pressed into useful service. The demand for high-speed production in the war industries, and the rapid advances made in radio technique during the war, have been responsible for an expanding interest in radio heating. Owing to the speed of heating and its uniform distribution, which results in an improvement in the quality of the finished product, the method was largely employed during the war in the glueing of plywood, the curing of pressed impregnated wood and the pre-heating of plastic moulding pellets. This method may

also be applied to the drying of paper, textiles and fibrous materials, tobacco, granulated cork and powders generally.

Where heat is applied externally in industrial processes, an appreciable time is necessary for the heat to penetrate into the interior of the material. The time taken to reach a given temperature varies as the square of the thickness; thus in the case of plywood assemblies a pack 5" thick will require 100 times as long as a pack $\frac{1}{5}$ " thick. (Generally speaking, ordinary hot pressing becomes impracticable at thicknesses much above 1").

With high frequency heating, on the other hand, the heat is generated internally in the pack and the bond usually becomes several degrees hotter than the adjacent material. In the case of the hot press, the material next to the source of heat is hotter than the bond, representing an undesirable waste of heat energy. Since with H.F. heating the heat is generated just where it is needed, there are no time lags, and both the setting of the bond and compression are accomplished in a few minutes, as against hours where heat is applied externally.

Radio frequency heating, or dielectric heating, is the name applied to the generation of heat in non-conductive materials by their losses when subjected to an alternating electric field. Such materials placed between metal plates become the dielectric of a capacitor and, as the capacitor is not perfect, losses take place in it. Various theories have been put forward to account for these losses; *e.g.*, if there are ions in a dielectric the electrostatic forces to which they are subjected will cause them to move, and work must be done in overcoming the forces resisting motion. Again, if the molecules behave as electric dipoles they will tend to align themselves with the field. As this is constantly changing in direction, they will be in continuous motion, and work must be done against the forces resisting change in direction. In either case energy will be drawn from the H.F. source and will raise the temperature of the dielectric; the power thus absorbed in producing heat is known as the dielectric loss of the material. As the energy dissipation due to the alternating electric field exists throughout the material, the heat generated is distributed uniformly throughout the mass.

The dielectric loss of the material can be calculated in terms of the physical constants of the dielectric and the character of the supply. In this connection the dielectric constant (K) is of importance; different materials when placed between identical electrodes will result in different total capacities, the dielectric constant is a measure of this effect and is the ratio of the capacity of two electrodes with the material as a dielectric to the capacity of the same electrodes in a vacuum. In the case of a simple parallel plate capacitor with air as the dielectric, the relation between the voltage across the plates and the current, I_c , is represented

by the vector diagram in Fig. (1). The voltage and current are 90° out of phase and there is no power loss. If the dielectric is placed between the plates, the capacitor is no longer a perfect one, as there is a loss in the dielectric equivalent to a shunt resistance (S)

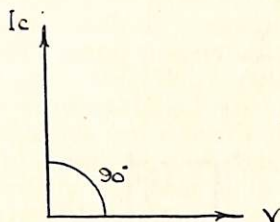


Fig. 1.

across the capacitor plates. The value of (S) varies with frequency, and the current (I_s) flowing through (S) is in phase with the applied voltage (V). Fig. (2) is the vector diagram for such an imperfect capacitor, the power factor of which is $\cos \theta$. Now $\cos \theta = I_s/I_c$, but provided it is small it may be written as :

$$\cos \theta = \frac{I_s}{I_c} \text{ or } I_s = I_c \cos \theta$$

The power loss (P) as heat in the dielectric is VI_s or $VI_c \cos \theta$ watts (1)

But $I_c = V 2 \pi f C 10^{-6}$

Where f = frequency (cycles) C = capacity of capacitor (μf)

and $C = \frac{2248 AK}{10^{10} d}$ (for parallel plates) (2)

Where A = area of one capacitor plate (sq. ins.)

d = distance between plates or thickness of dielectric (ins.)

K = dielectric constant.

Therefore

$$I_c = \frac{2248 AK 2 \pi f V}{10^{10} d} = \frac{14.12 AK f V}{10^{13} d} \text{ amps.} \quad (3)$$

and the power loss $P (= VI_c \cos \theta)$ from equation (3)

$$= 14.12 \times 10^{-13} \frac{A f V^2 K \cos \theta}{d} \text{ watts} \quad (4)$$

The energy required to produce any desired rate of heating in a material of given weight and specific heat can be calculated from the following equation :

$$P = \frac{MS (t_2 - t_1) 10^3}{56.9} \text{ watts mins.} \quad (5)$$

where P = energy required, watt minutes.

M = weight of material to be heated, pounds.

S = mean specific heat.

$(t_2 - t_1)$ = temperature rise, °F.

from which

(6)

$$(t_2 - t_1) = \frac{56.9 P}{MS 10^3} \text{ °F.}$$

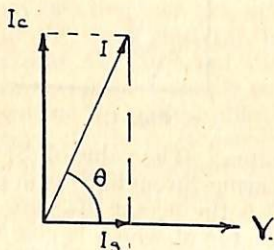


Fig. 2.

From equation (4) it will be seen that the power loss in the material is proportional to the product of its dielectric constant K and power factor $\cos \theta$. The quantity $K \cos \theta$ is called the loss factor of the material. The power factor of most materials varies with frequency and temperature and in the case of some materials, such as wood, with moisture content also. Thus the power factor used in the above equations should be measured at or near the operating frequency and at a known temperature. The dielectric constant changes relatively slowly with frequency and temperature and can be taken from published tables with a fair degree of accuracy. It varies, however, with the moisture content. It should be noted that in some cases the power factor may decrease considerably as the temperature increases, owing to the dielectric properties of the material being improved by the heat. This may be an advantage or a disadvantage, according to whether it is desired to dry off the solvent quickly and complete a polymerization at a higher rate, or *vice versa*.

It will also be seen from equation (4) that with the material with a constant loss factor ($K \cos \theta$), the rate of heating (assuming that all the power lost in the dielectric is used in raising the temperature of the material) increases in proportion to the supply frequency, and that at a given frequency it varies with the square of the voltage.

The above equations hold only for uniform electric fields. Since the field at the edges of the electrodes is always distorted, a good approximation is possible only when a minimum dimension of the electrode is large compared to the distance between the plates.

Because of corona and arcing effects, the maximum voltage applied to the electrodes is approximately 14-15 kV/r.m.s., with 2-3 kV/r.m.s. per inch of separation, being the maximum for smaller spacings. Dielectric constants for most materials fall in the range of 2 to 6, but may vary from 1 for gases up to 1000 for some ceramics, while power factors usually lie between 0.02 and 0.07, but may be as low as 0.00015 (mica, polystyrene) or as high as 0.15 (asbestos). Gases and pure water have power factors that are almost zero and are not adapted to be heated by this method.

An analysis of the above equations will indicate for some materials the desirability of very high frequency. However, valves and equipment commercially available at the present time limit the maximum frequencies obtainable to approximately 200 megacycles for power outputs up to 100 watts, 30 megacycles for power outputs up to 40 kilowatts, and 4 megacycles for high power ratings. It should be noted that at the high frequencies, the maximum electrode dimensions must be limited to at least one-eighth of wave length in the dielectric to avoid standing waves which result in non-uniform heating. Formula for determining the wave length for air is :

$\lambda = 300/f$, where λ is the wave length in meters and f the frequency in megacycles.

2. Data on Wood.

The average engineer is not greatly concerned with timber, and it is for this reason that, generally speaking, its detail characteristics are not fully appreciated. Most substances used by the electrical engineer have fairly steady moisture content. Timber, on the other hand, is obtainable in so many varieties and may even have moisture contents as high as 80%. It is important to remember that the moisture content is expressed as a percentage, by weight, of the dry content of the wood. In order to obtain the weight of a piece of timber at a given moisture content, it is necessary to multiply the fractional moisture content plus 1, by the dry weight. The moisture content varies greatly with atmospheric conditions, and this is shown in Fig. 3. It is therefore very necessary to moderate atmospheric conditions in plywood and improved wood factories.

The moisture content of veneer is controlled between 5% and 15%, depending upon the application.

This variation in moisture content greatly affects the electrical characteristics of the wood—this can be seen in Fig. 4, which shows the change in the dielectric constant K at 50 c/s, with variation in moisture content of veneers. With a 10% moisture content the dielectric constant is 4.8, but as the wood is dried it falls gradually to less than half the value. An even greater change is to be seen with power factor, as is shown in Fig. 5; values being

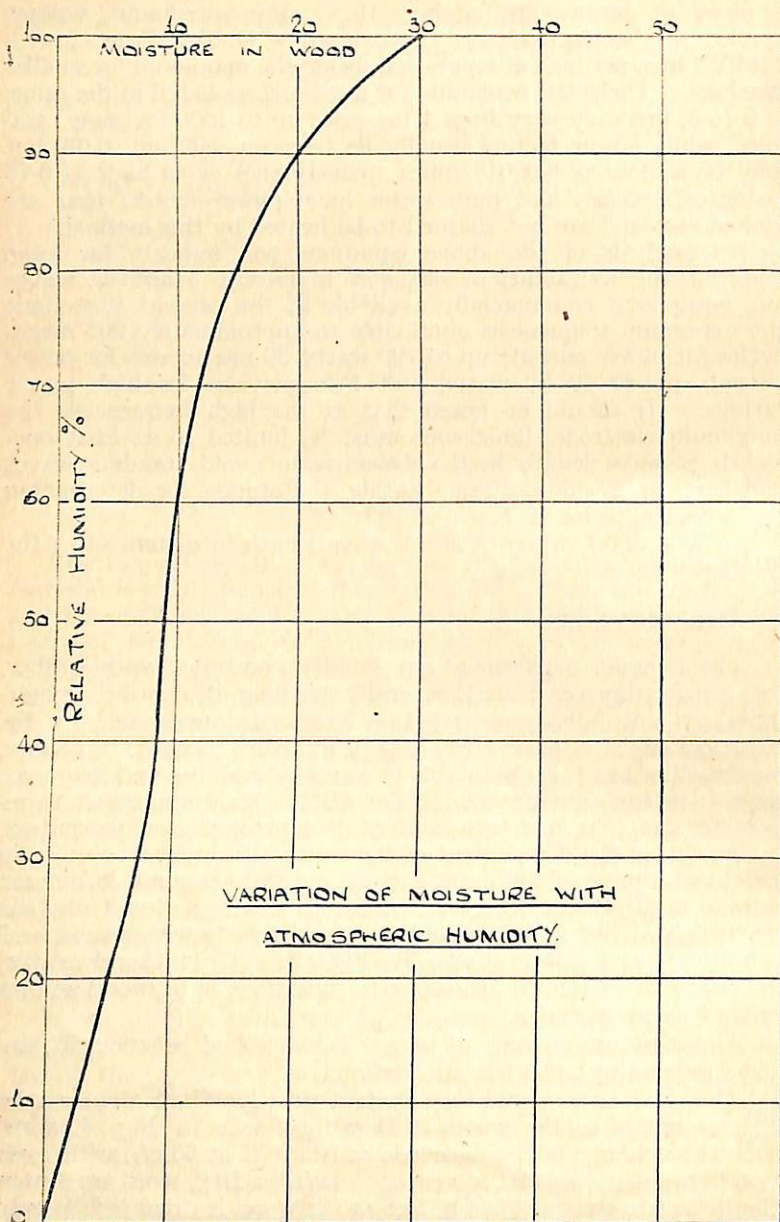


Fig. 3.

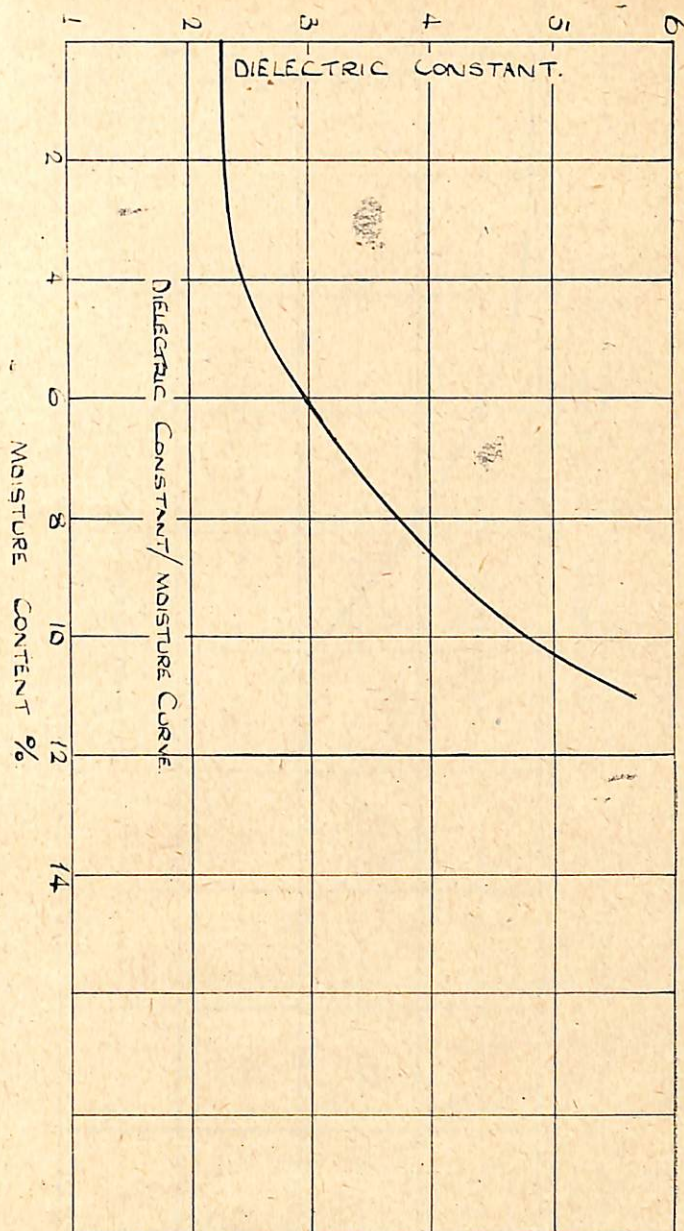


Fig. 4.

ELECTRONIC HEATING

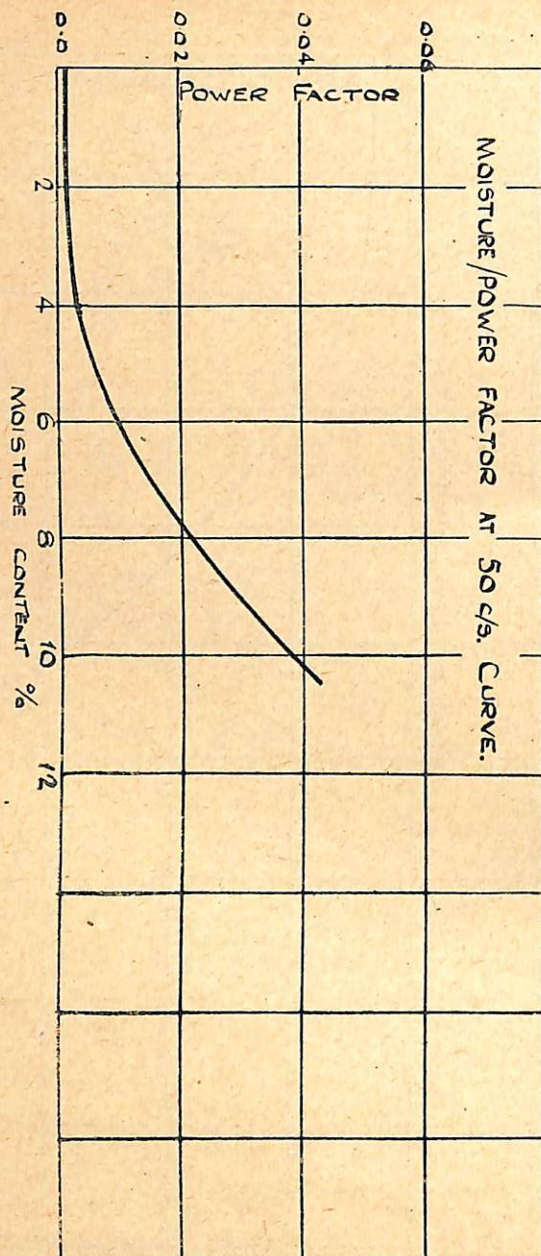


Fig. 5.

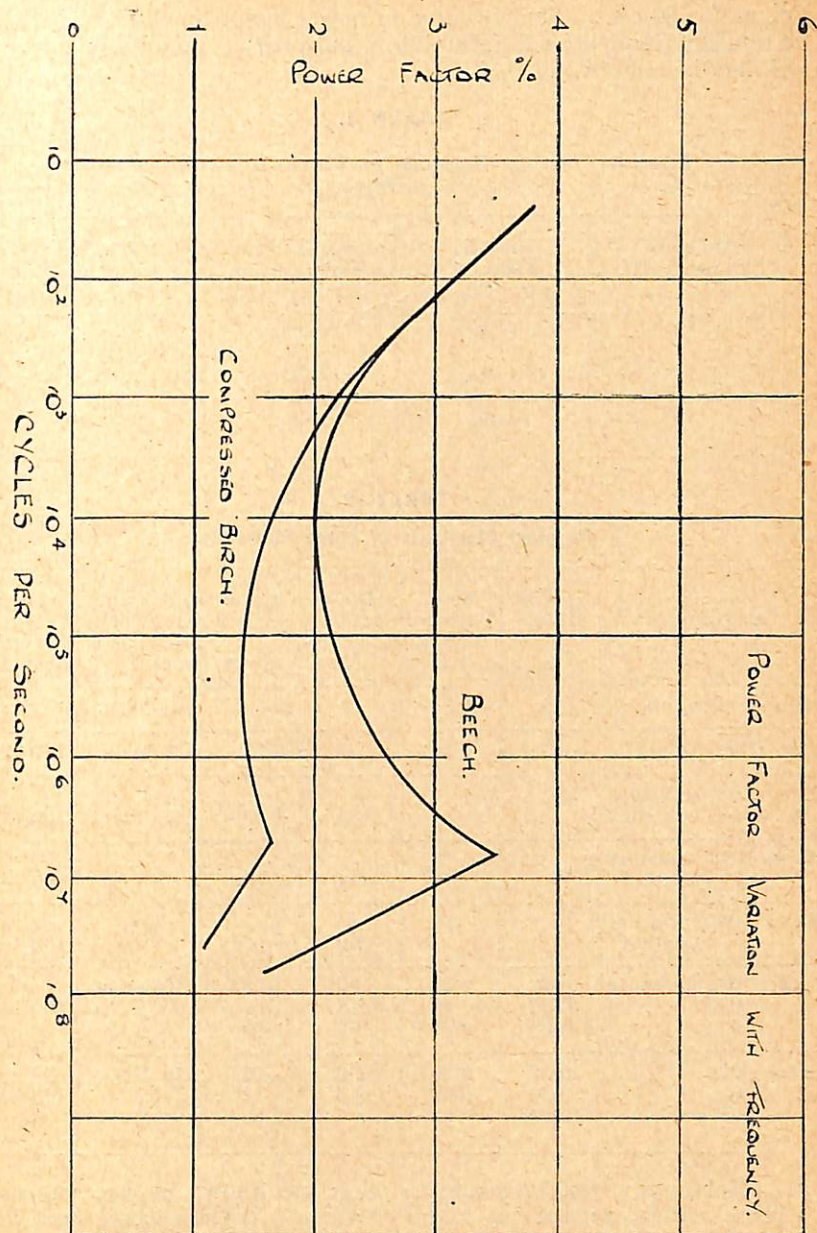


Fig. 6.

given for 50 c/s. The variation of power factor for dry wood with a range of frequencies is not uniform, but presents an unusual curve, as may be seen in Fig. 6.

TABLE 1.

Effect of Moisture Variation on Characteristics of Laminated Wood.

Moisture Content %.	Specific Gravity Grams./Cu. cm.	Specific Heat Calories per Gram. per °C.	Dielectric Constant (Along grain).
0	0.56	0.324	2 - 2.5
5	0.59	0.356	2 - 5.3
15	0.69	0.412	9 - 15

TABLE 2.

Physical Constants of Some Materials.

MATERIAL.	Specific Heat. S	Relative Density p	Dielectric Const't K	Power Factor. $\cos \theta$	Frequency at which K & $\cos \theta$ measured.	Usual temp. to which heated °C.
Phenolic glue liquid	0.8	1.23	10	> .50	10 Mc/s	140°C.
Urea Glue Liquid	1.0	1.30	26	.85	10 Mc/s	100°C.
Oak 10% moisture content			3.3	.039		100-140°C.
Maple 10% moisture content			4.4	.033		100-140°C.
Birch 10% moisture content			5.2	.065		100-140°C.
Spruce 0% moisture	0.32	0.37	2.2	.052	45 Mc/s	100-140°C.
6% "	0.36	0.40	2.5	.070	"	
10% "	0.39	0.42	3.2	.090	"	
Beech 0% "	0.32	0.56	2.0	.02	10 Mc/s	100-140°C.
6% "	0.36	0.61	3.0	.11	"	
10% "	0.39	0.63	5.0	.38	"	

Reference must be made to what are known as $p.c.$ values. These are the product of p and c , where p is the specific heat in calories per gram per °C. and c is the density in grams per cu. cm. For most timbers the $p.c.$ values fall between 0.25 and 0.35.

Fig. 7 takes the limiting values of $p.c.$, namely, 0.25 and 0.35 and shows the power in watts per cub. in. plotted against the time in minutes to reach wood temperature of 160°C . (320°F).

3. Glues.

The thermosetting glues most widely used in the wood-working industry to-day are either of the synthetic urea resin type or of the synthetic phenolic resin type. The urea resin glue can be obtained in the form of a liquid ready for use, or in the form of powder, which must be dissolved in water before using. Fig. 8 shows a typical curing time-temperature curve for a catalyzed glue of this type.

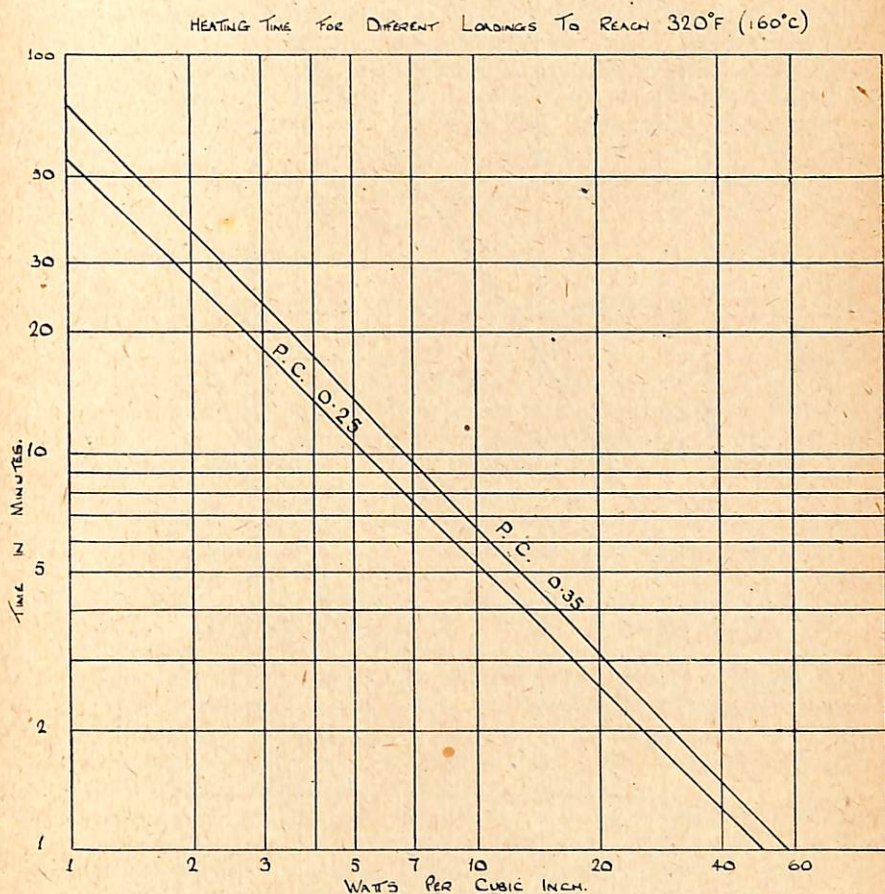


Fig. 7.

ELECTRONIC HEATING

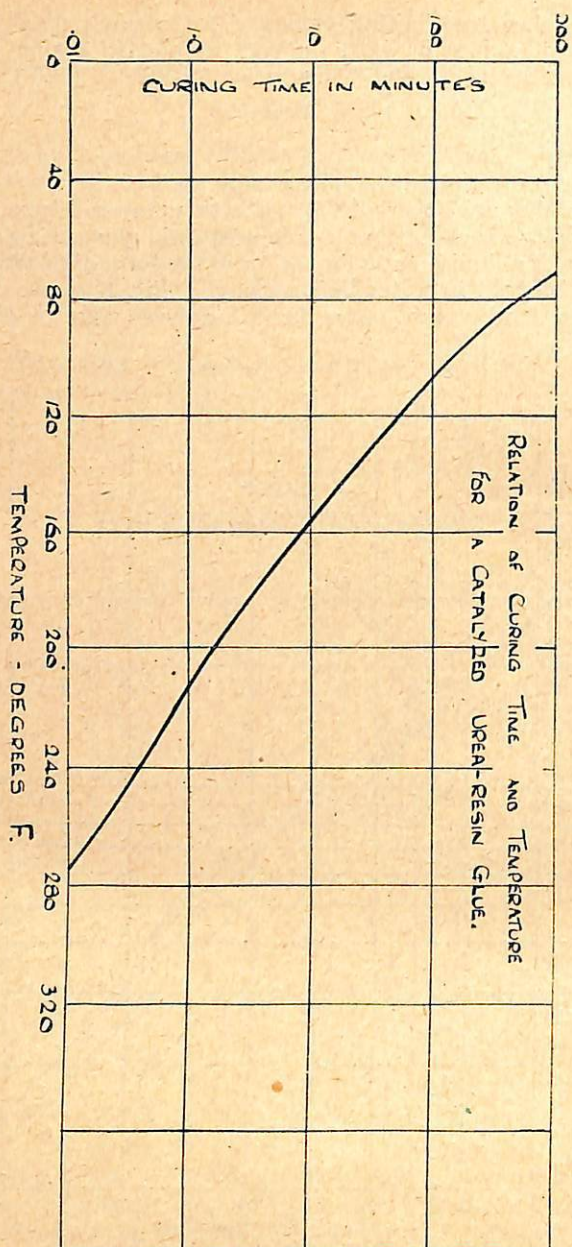


Fig. 8.

It will be noted that for a temperature of 220°F. the curing time is about one minute, whilst at 75°F. the curing time is about 13 hours. Although the curing time could be further reduced by the addition of more catalyst, the glue may then set too quickly at room temperature to be of any practical use. The pressures of 15 lbs. per sq. inch or greater should be maintained during the glueing cycle, so that irregularities in the adjacent wood surfaces may be eliminated.

If the bond is properly cured it is highly water resistant at ordinary temperatures but not at elevated temperatures. Urea glue is lower in price than phenolic glue and can be extended by mixing with wheat flour, wood flour, or other fillers. Phenolic resin glue can be obtained in the form of liquid, a film, or a powder; the powder must be dissolved in water or alcohol before use. For best results this type of glue generally requires a bonding temperature of 280°-300°F., maintained for several minutes, with an applied pressure as great as the wood will stand without damage. The resulting bond is stronger than the wood, and resistant to water even at its boiling point. Specific information on the curing time-temperature for any particular glue can be obtained from the glue manufacturer.

4. Heating Dimensions.

The dimensions of the piece of dielectric material are important in that they may influence application as to frequency, rate of production, or electrode design. In general, dielectric heating becomes attractive when the thickness of the material is sufficient to make it difficult to heat the material throughout by conventional means. In terms of inches this will vary with the thermal conductivity of the material. The thickness of the material must be reasonably uniform, if uniform heating is desired.

If the work is of such shape, *e.g.*, wedge shape, that two pieces of material can be placed in complementary positions and result in the thickness being uniform, the material will heat evenly. Special techniques in electrode design and arrangement may sometimes be used when dealing with materials of irregular thickness. The relation of thickness and voltage will be discussed under voltage.

The area of the material to be heated will limit the frequency which may be used, in two ways. The capacitive reactance of a large area may become sufficiently low as to make tuning of the load extremely difficult, if not impossible. The current involved may also reach magnitudes difficult to handle.

The length of the load may be such as to produce standing waves—these will be discussed under frequency limitations.

Sometimes it is possible to scan the material, thus reducing the electrode area to a value which promises convenient adjustments and frequencies sufficiently high to produce desired rate of heating.

By scanning, it is understood that when matching conditions are such that it is impossible for the electrode to cover the whole area of the joint, or the material being heated or glued, the material is either passed beneath the electrode, or the electrode moved over the material itself, *i.e.*, scanning.

For example, we might consider the case where it is desired to edge joint a number of small strips of wood to make wide boards of indefinite length. Obviously, in this case we shall have a limitation of matching capacity from electrode to generator. If it is desired to make up a board 36" wide, it may be found that the maximum electrode area permissible would be in the order of 36" x 4" with a 1½" gap. In order to overcome this limitation of electrode size, the wood to be jointed is passed beneath the electrode and the electrode thus scans the work.

Occasional complications are encountered where a particular area can be heated if the material is stacked, increasing the thickness dimension, thereby reducing the capacity of the load.

For rapid calculation the capacity of the load can be determined from the following formula :—

$$C = AK/4.45 d$$

where A = useful area of one plate in sq. ins.

K = dielectric constant.

d = gap between plates in inches.

This formula is a variation of that shown under (2), but gives the same results and is easier to operate.

It should be noted that the useful area is approximately equal to the area of the smaller plate when the square root of the area is large compared with the gap.

5. Frequency.

In general, since the amount of energy produced within the material is proportional to frequency the desire is to use as high a frequency as possible ; a compromise is usually necessary, however, due to one or more limitations.

The effect of large areas and low capacitive reactance was considered previously. The length of the material may be such as to produce uneven heating due to standing wave effect. The higher the frequency used, the greater the probability of unequal voltage distribution over a given length of area. If the longest dimension of the electrodes is a small fraction of a wave length, or if the material is scanned, this effect is minimised. Ordinarily, if the longest distance from the point of connection to the edge or corner of the high voltage electrode is less than $\frac{1}{16}$ of a wave length, very little trouble will be experienced. Heating will be sufficiently uniform to produce a variation of less than 20% over the area involved. In some processes this may be intolerable, restricting the maximum frequency, or maximum dimensions of the work, to

a still lower value. The maximum frequency which can be used without exceeding the above variation in heating can be determined from the formula :

$$f = \frac{62.5}{d \sqrt{e'}}$$

where f = frequency in m.c./s.

d = maximum distance from point of connection to edge of corner of high voltage electrode, feet,

and e' = dielectric constant of material (specific inductive capacity).

Another limitation occasionally encountered is that of generator design for high power and high frequency. From a practical standpoint, at the moment it appears undesirable to use frequencies above 20 m.c./s where powers above 20 kW. are involved.

It is advisable that there shall not be a change in voltage between any two points along the length greater than 10%, and preferably this change should be less than this, as it is equivalent to a power variation of 20%. Fig. 9 is given to show the maximum frequency that may be used for any length with a 10% voltage change.

6. Voltage.

The power input to the material is proportional to the voltage squared, hence if the voltage is increased sufficiently considerable power could be applied to the work at relatively low frequencies.

Two factors limit the voltage which may be applied. The total voltage between electrodes should be kept under 15,000 volts. It is not impossible to use voltages above this value, but the additional precautions necessary to avoid corona and arc-overs are more expensive than some other compromise of the engineering factors. The voltage gradient, *i.e.*, the voltage per inch permissible across the material, may be a limiting factor. The H.F. voltage which will puncture a given dielectric material is generally much lower than the 60-cycle voltage which a material will stand. It appears desirable to keep the voltage gradient below 2000 volts per inch in porous materials, and below 5000 volts per inch in less porous materials.

Another type of voltage limitation may be reached in some applications where it is impossible to have the electrodes in contact with the material. This gives rise to a condition in which the space between the electrodes is occupied by two materials of widely different dielectric constants. The potential distribution in these cases may be such as to cause a breakdown of the surrounding medium (usually air).

An example of voltage limitations may be observed from the following :—

It is required to heat a board of laminated wood using a 60-cycle supply. The capacity of the board is 150 p.f. It has already been

MAX. FREQUENCY POSSIBLE FOR DIFFERENT LENGTHS OF LOAD IF VOLTAGE VARIATION = 10%.

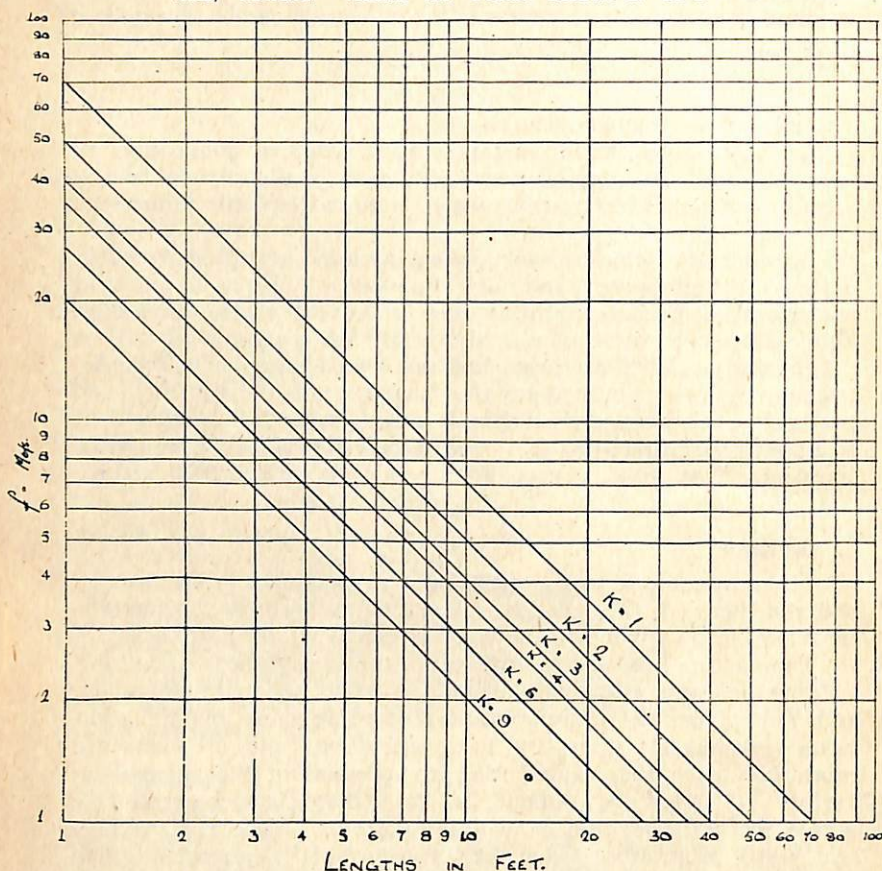


Fig. 9.

estimated that a power of 6000 watts for 8 minutes will heat the board to the desired temperature. The power factor of the wood is assumed to be 0.05. What output voltage is required?

- (1) First of all, it is necessary to calculate the capacitive reactance X_c .

$$X_c = \frac{1}{2 \pi f c}$$

$$f = 60 \text{ cycles/sec.}$$

$$c = 150 \text{ p.f.}$$

$$= \frac{1}{2 \pi 60 \cdot 150 \times 10^{-12}}$$

- (2) Next, equivalent resistance R_p is calculated from the formula :

$$\begin{aligned}
 R_p &= \frac{\text{Capacitive reactance}}{\text{Power factor}} \\
 &= \frac{10^{12}}{2 \pi 60 \quad 150 \times .05} \\
 &= \frac{10^{12} \times 10^{-2} \times 10^2}{2 \pi 6 \times 15 \times 5} = \frac{10^{10}}{9 \pi} \\
 &= 352 \times 10^6
 \end{aligned}$$

- (3) Next, the current has to be calculated. The power is known, namely, 6000 watts.

$$\text{Power } P = i R^2 R_p$$

$$i R^2 = P/R_p$$

$$\begin{aligned}
 i R &= \sqrt{\frac{P}{R_p}} = \sqrt{\frac{6000}{352 \times 10^6}} = \sqrt{\frac{.006}{352}} \\
 &= \sqrt{.000017} \\
 &= .00413 \text{ amps.}
 \end{aligned}$$

- (4) Finally, voltage is calculated from expression,

$$E = i R R_p$$

$$E = .00413 \times 352 \times 10^6$$

$$= 1,460,000 \text{ volts approximately.}$$

This figure is, of course, too high, because the frequency chosen was too low. Such a voltage would puncture the boards, even assuming that it could be insulated from the press metal work. It was decided, therefore, to repeat the calculations, using frequencies of 1 megacycle per second and 10 m.c./s respectively.

The following is a table of complete results :—

TABLE 3.

DESCRIPTION.	EXAMPLE 1.	EXAMPLE 2.	EXAMPLE 3.
Power required ...	6000 watts	6000 watts	6000 watts
Time required ...	8 mins.	8 mins.	8 mins.
Capacity	150 p.f.	150 p.f.	150 p.f.
Power factor ...	0.05	0.05	0.05
Frequency chosen ...	60 cycles	1×10^6 cycles	10×10^6 cycles
Capacitive reactance	17.7×10^6	1010	106
Equivalent resistance	350×10^6	20,200	2120
Current—amps. ...	4.13×10^{-3}	0.545	1.68
Voltage—volts ...	1.4×10^6	11,000	3480

7. Loss Factor.

This is a term commonly used to express the degree to which materials will absorb energy by dielectric heating technique. It is easily measured by means of proper equipment. As the loss factor approaches zero, it becomes increasingly difficult to transfer power into the material. A practical lower limit in the loss factor of materials which can be heated effectively appears to be between 0.005 and 0.01. Pure polystyrene, quartz, and certain other low loss materials, have loss factors considerably below this value and are extremely difficult to heat by dielectric methods. The upper limit probably blends into the range where material becomes sufficiently conductive as to respond to inductive fields, although some skin effect will probably be noted before this limit is reached.

8. Electrodes.

A whole treatise could be written on electrode design. One point worthy of mention is the fact that heat is not generated in the electrodes to any appreciable extent, by the dielectric heating process. The electrodes may be heated by heat transferred from the dielectric material in process; often this is undesirable, due to the temperature reduction of the adjacent material, and may become a limiting factor in some processes. Various simple methods are in common use to minimise this effect. To establish operational or production standards it is normally necessary to determine (a) the optimum frequency for any individual electrode set up, and (b) the ratio of power-frequency-time required to satisfactorily cure the glue lines of a joint.

Close investigation must be made into these problems in individual applications of radio frequency heating.

It further appears that the future of dielectric heating, applied to wood processing, depends to a great extent on careful design of equipment for specific purposes.

It is suggested that any equipment should have the following facilities, which are considered necessary :—

- (1) Easy change of frequency within the range 5 mc/s to 30 mc/s.
- (2) Variable coupling of output.
- (3) Positive output indication.
- (4) Simplicity of controls, with push-button operation for production purposes and automatic heat-timing cycle.
- (5) Stability of tuning when under working conditions.
- (6) Provision for output to be either unbalanced or balanced with respect to earth.
- (7) Easy access for maintenance and/or repair purposes.

There are numerous ways of arranging the H.F. electrodes ; they can be placed either parallel to the faces of the veneers, or parallel to the edges of the veneers. It is claimed that the latter method needs considerably less power. Four of the typical arrangements for electrodes are shown in Figs. 10, 11, 12 and 13, and electrode lengths to as much as 50 feet have been quoted.

In a recent article it was stated :—

“To date a great deal of literature has been published on high frequency electrostatic heating. Unfortunately much of this literature is of a controversial nature. Different groups, although in agreement on the fact that heating is caused by molecular friction within the material, offer differing explanations of the electrical phenomena involved. One school of thought claims that, due to the frequency involved, standing waves appear along the electrodes, with a resulting non-uniformity in heating. Other groups claim that half of a standing wave exists between the electrodes, and the other half between the electrodes and the machine. Again, this is supposed to result in non-uniform heating, with a concentration of heat existing mid-way between electrodes. Finally, another group, probably the largest, insists that any unusual heat concentration usually at the centre, is due to migration and concentrates of moisture within the wood.”

It is extremely unlikely that the steam-heated press will fall into disfavour for a long time to come, and even the advocates of the H.F. method are satisfied with “steam” or “high pressure hot water heated platens” for thin laminated boards. There does, however, seem to be a definite case for the application of the H.F. method to the manufacture of thick boards. The disadvantages

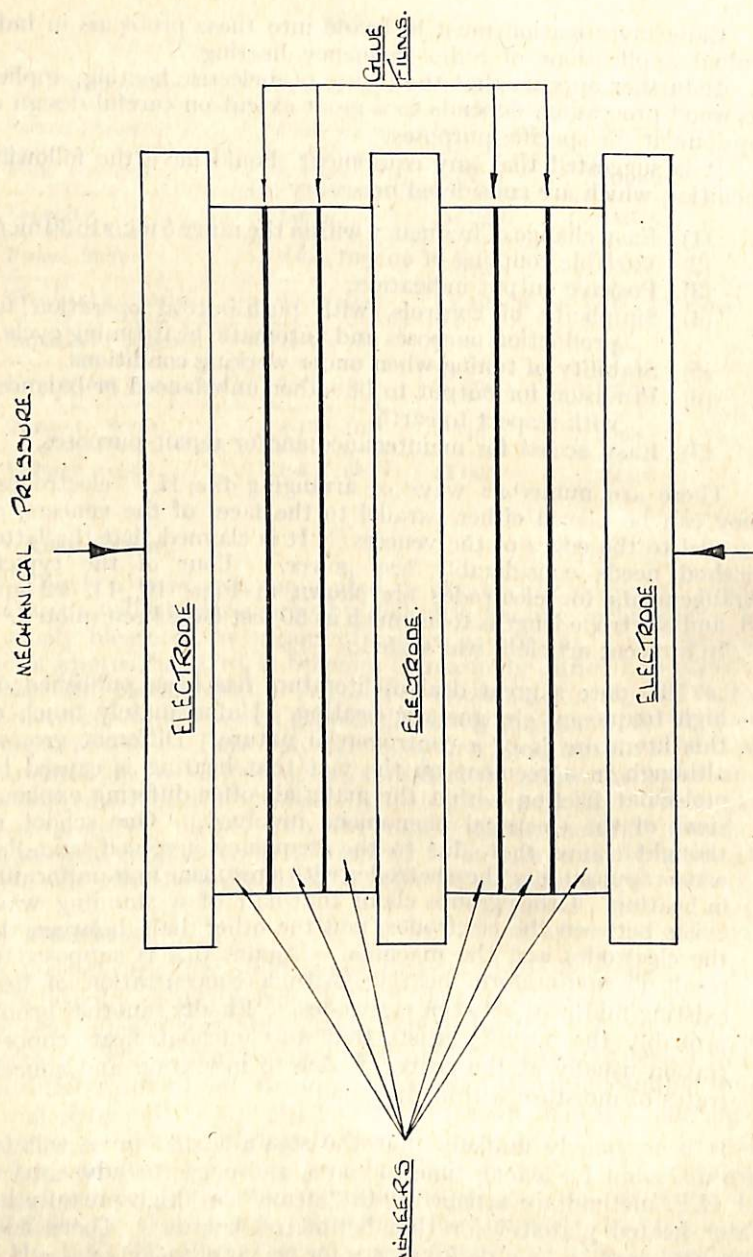


Fig. 10.—Arrangement with Parallel Electrodes.

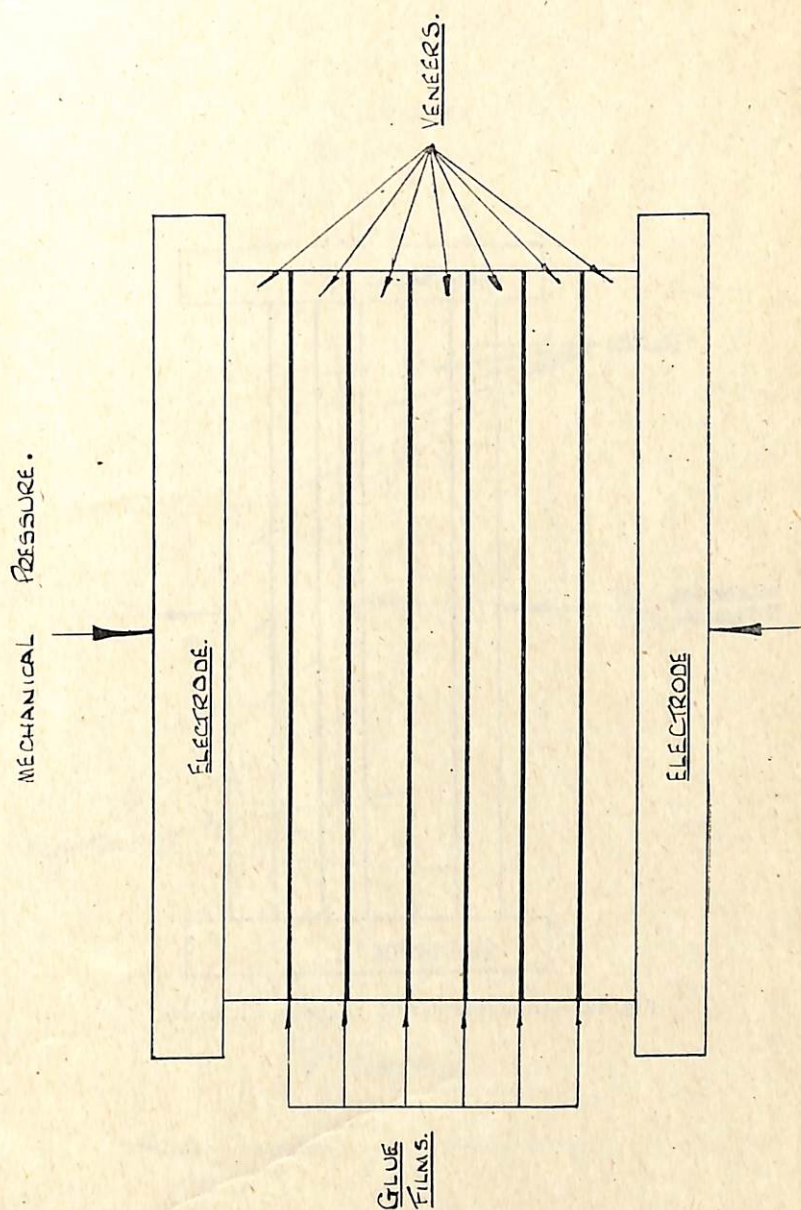


Fig. 11.—Arrangement with Parallel Electrodes.

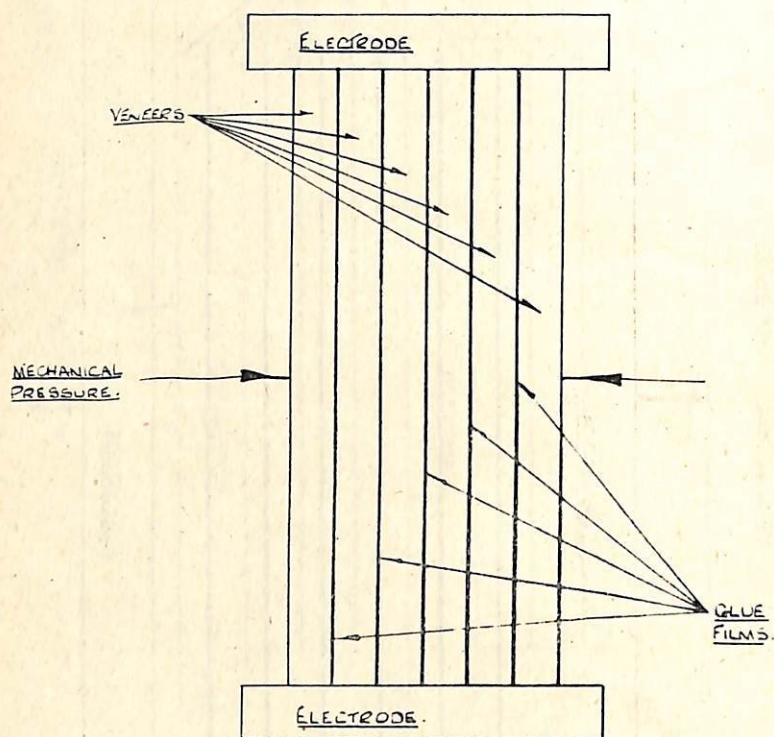


Fig. 12.—Arrangement with Edgewise Electrodes.

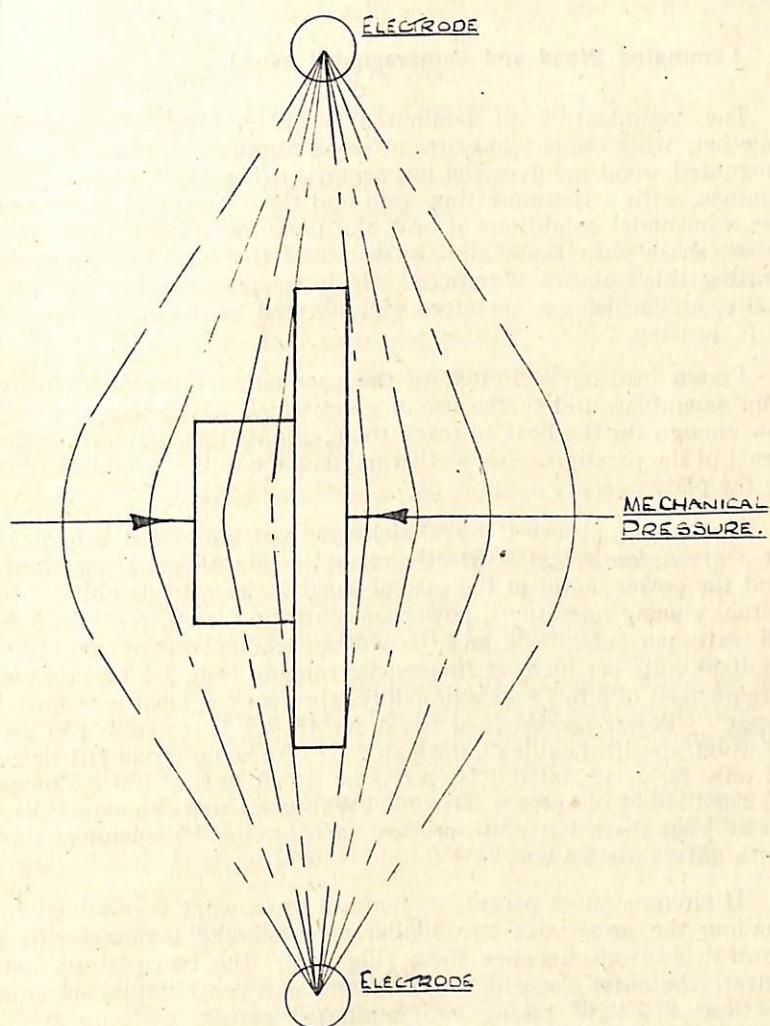


Fig. 13.—Arrangement with Edgewise Electrodes.

inherent in the heated platen method for thick boards are the long time taken for the heat to reach the centre of the pack, and the risk of the outer layers becoming overheated or even burnt.

9. Laminated Wood and Compregnated Wood.

The manufacture of laminated wood involves the glueing together, while under pressure, of wood laminae. That of compregnated wood involves the impregnation of a block of wood, or laminae, with a thermosetting resin and the subsequent setting of the resin under conditions of heat and pressure. Both these processes share with those already discussed the need of uniformly heating thick blocks of material which are poor conductors thermally, and which are therefore well adapted to the application of H.F. heating.

Platen heating is limited to the production of comparatively thin assemblies and to the use of glues which set at temperatures low enough for the heat to reach them, situated as they are in the heart of the pressing, without thermal damage to the wood adjacent to the platen.

The power absorbed by a dielectric and converted into heat at a given frequency is directly related to its dielectric constant, and the power factor in the case of wood varies considerably. In actual glueing operations, power concentration is varied from 5 to 75 watts per cubic inch, and the voltage gradient range from 1000 to 4000 volts per inch, at frequencies ranging from 1.5 to 45 mc/s. Frequencies of 5 to 15 mc/s probably represent the most economical range. Power needed is of the order 45 B.T.U. to raise 100 lbs. of wood, specific heat 0.45, through 1°F. Allowing for an efficiency of only 50%, 42,500 B.T.U. per hour would heat a 100 lb. block to 220°F. in 9½ minutes. Two 300 kW. heating units are equivalent to at least three hot plate presses, each having 15 openings and with automatic loaders.

If circumstances permit, economical press work is obtained by loading the press with two similar assemblies of laminae with a central electrode between them (Fig. 10); the two platens constitute the outer electrode in, for example, a press employing twin sections 8' x 4'10" taking two laminated panels, each up to 9" thick, with an electrode between them. Temperatures used are mostly 160° to 180°F., but may on occasion rise to 300°F. It has been proved that the method of placing the high frequency electrode parallel to the edges of the veneers involves the consumption of considerably less power than that in which it is placed parallel to their faces (Fig. 12).

Compared with hot plate glueing :—

- (1) Heat is uniformly distributed.
- (2) Time cycles are usually much shorter and are independent of wood thickness.
- (3) Thicker sections can be glued.
- (4) Higher temperature setting glues can be used.
- (5) Temperature can be more closely controlled.
- (6) Surface of wood is not dried out.
- (7) Cheaper presses are used.
- (8) Temperatures in the glue line run higher than in wood.
- (9) High surface temperatures are avoided and steam blisters do not form, consequently wood need not be so thoroughly dried as is customary.
- (10) Product is flatter, and is not case-hardened.

Compared with cold glueing :—

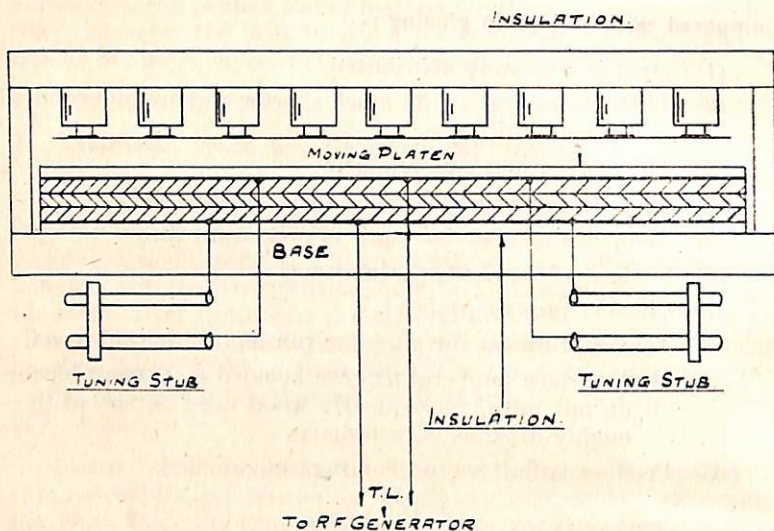
- (1) Very substantial reduction in time cycles.
- (2) Allows use of phenolic glues.
- (3) Makes for better and more consistent unions.
- (4) Requires fewer presses or jigs.
- (5) Large savings in floor space are possible.

It is pointed out that, if desired, H.F. power could be used merely for pre-heating to the desired area temperature, getting the whole mass uniformly heated throughout, the desired temperature being then maintained by conventional means.

If heat insulation is used between work and electrodes, this must be of the electrical low loss type. (Fig. 13 shows the distribution of the electrical field produced around a simple joint).

10. Standing Waves.

In cases in which long lengths of wood are being treated, the length of the wood becomes comparable to the wave length at operating frequency; this leads to the formation of standing waves and so to unequal heating. Electrical means are available for overcoming this condition, as indicated by Figs. 14 and 15, wherein tuning stubs are used to tune the load and reduce the voltage variation along the press. Much narrow waste timber can now be economically joined into wide boards. A synthetic

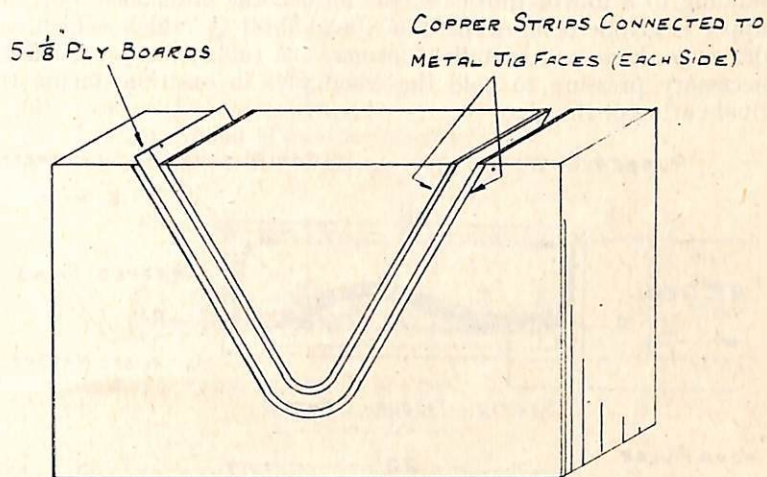


TUNING INDUCTANCES - $\frac{1}{2}$ COPPER TUBES MOUNTED ON -
STAND-OFF INSULATORS.

Fig. 14.—Press for Glueing Long Spars (16½-ft.).

glue is smeared along the edges of the boards, and H.F. heat is used to set the glue at speeds up to 5 ft. per minute for boards made up to 36" in width and having up to 37 separate joins.

In moulding plywood around a former by the rubber bag process, staples are driven in to keep each layer in place and are later removed one by one before curing. This takes time and trouble and leaves numerous small holes. Moreover, a broken staple in the work may puncture the rubber moulding bag. A spot glueing tool has been devised using H.F. current, which eliminates the need for staples. Both electrodes are on the same side of the work; there is a central electrode and a concentric outer electrode spaced from it. Lines of electric field spread out beyond the end of the central electrode where they are most concentrated and on their way to the other, pass through the work, where they produce local heat. An application of one or two seconds suffices to set the glue, thus the assembly is held together until ready for the final curing. The glue spots, not being fully cured, soften at curing temperature, allowing first that small degree of relative movement to take place between the plys to ease local stresses before the final irreversible hardening occurs.



WOOD JIG FACED WITH METAL

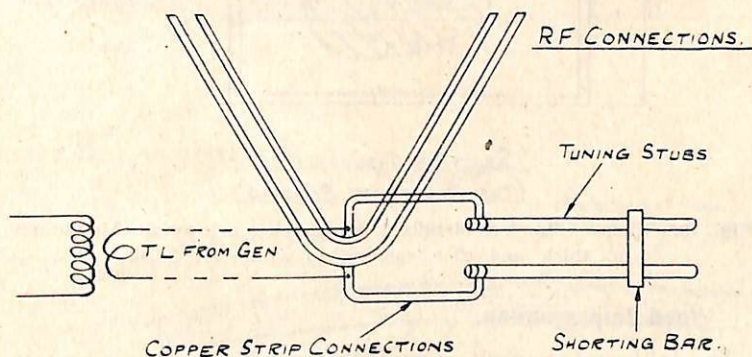


Fig. 15.—R.F. Jig—Tuning Stubs used to Parallel Tune the Load.

Fig. 16 illustrates the general section of the former used for this process, and it is of interest to note that the final curing was also effected by R.F., the wooden base of the former itself being metalised by spraying a layer of aluminium $\frac{1}{8}$ " thick and then sanding to a mirror finish. This formed the lower electrode, the upper electrode being formed of a lead sheet $\frac{1}{16}$ " thick, which was drawn to shape on a metalised former. A rubber bag provided the necessary pressure to hold the wood plys in position during the final curing of the glue.

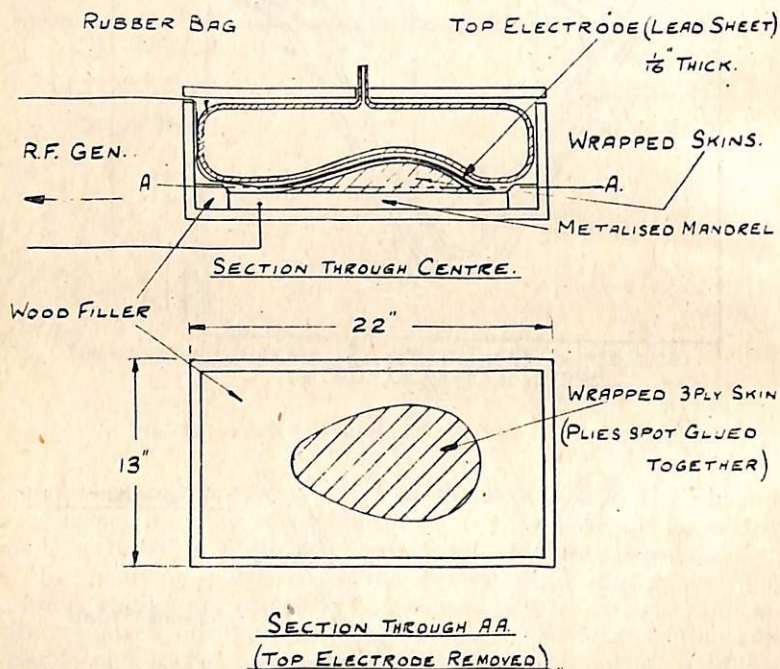


Fig. 16.—Blister—Mandrel Metalised by spraying a layer of Aluminium $\frac{1}{8}$ -in. thick and then sanding to a mirror finish.

11. Wood Impregnation.

The following example of propeller manufacture may be taken to illustrate the use of H.F. heating in preparing compregnated wood.

A blank was heated by this method to 230°-260°F., which took 4 minutes. The blank was then placed in a die and pressure applied; the material being soft the die closed only for 3 to 4 minutes, as compared with 2½ hours by standard methods and 4 hours for heat to reach the centre when the preform was put in

glue. The finished article was also of superior quality, and free from internal stresses. Advantages in this connection are :—

Compared with standard methods :

- (1) Considerable reduction in overall time cycle.
- (2) Reduction in number of dies required.
- (3) Large reduction in internal stresses.
- (4) Close control of temperature.
- (5) Less critical operation.
- (6) Less likelihood of exothermic reaction.
- (7) Higher temperature setting glues can be used.

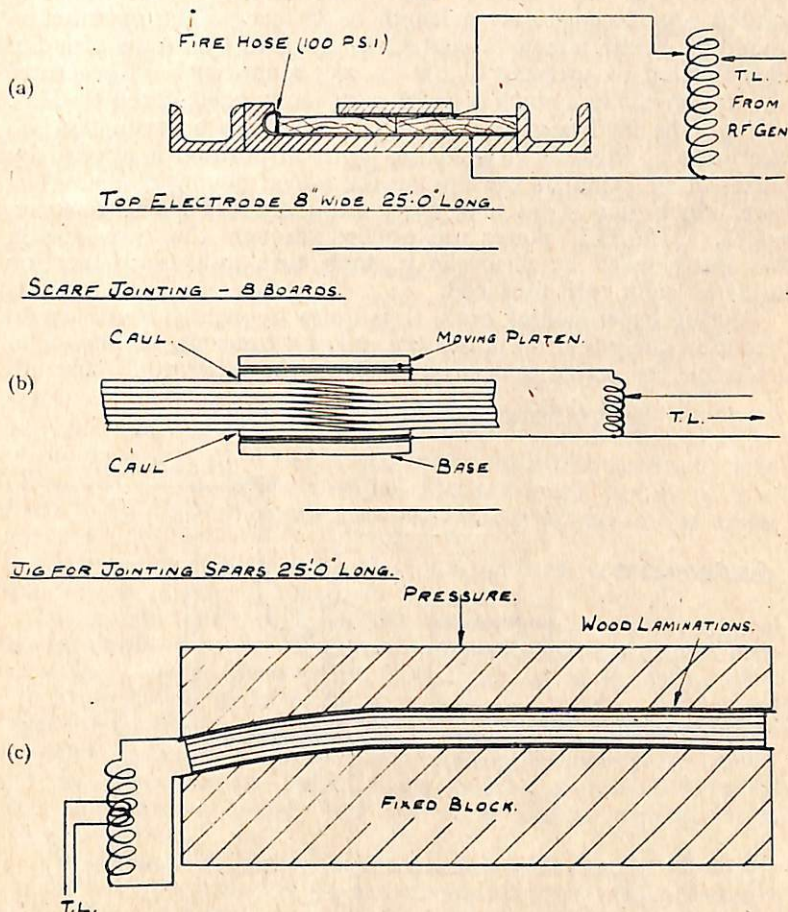


Fig. 17.

- (a) Edge jointing showing method of applying pressure to joint.
- (b) Scarf jointing 8 joints at one time.
- (c) Jig for jointing aircraft spars with 8/1 coupling arrangement.

Compared with autoclave method.

- (1) No autoclave required.
- (2) Dimensions not limited by size of autoclave.
- (3) Time cycle greatly reduced.
- (4) Fewer forms needed.
- (5) Fewer operations involved.
- (6) Less floor space needed.
- (7) Higher temperature setting glues can be used.
- (8) Inconvenience much reduced.

Additional applications of H.F. heating in wood processing are shown in Fig. 17. In the upper section, two boards are being jointed edge to edge over a length of 25 feet. The pressure required to ensure adequate contact is provided by means of a fire hose inflated by pressure to 100 lbs. per square inch. The centre illustration shows a stack of eight scarf joints being cured by H.F. current, the field passing through the glue lines between the two electrodes. Pressure to hold the joints in position is applied by means of air cylinders working on the upper moving platen. The lower illustration shows a jig for jointing aircraft spars 25 feet in length. The H.F. power was applied through the transmission line and coupled by means of a single turn inductance rotating inside an eight turn tank coil.

During experimental work, it is quite frequently necessary to determine the power output at the end of a transmission line, or to determine the actual power output from the generator. Fig. 18

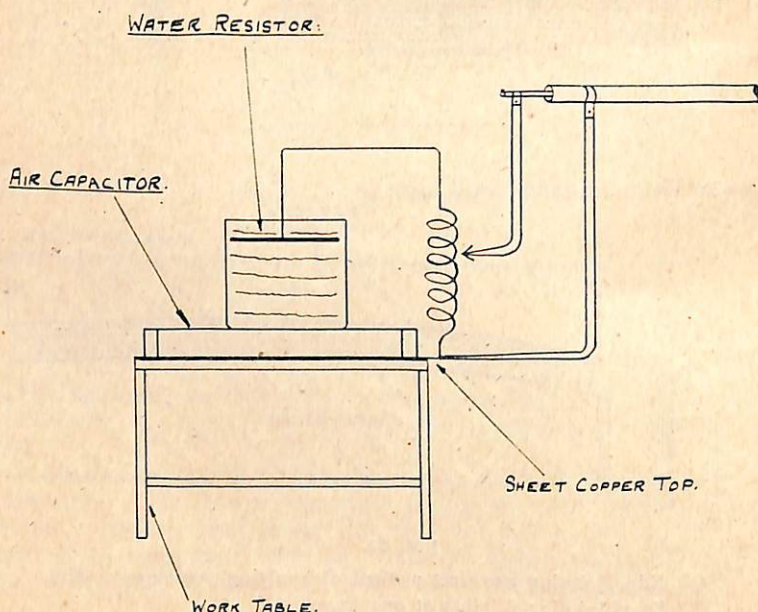


Fig. 18.—Dummy Load.

shows the method of using a dummy load in place of electrodes when it is desired to make tests of the generator performance. With the capacity of the water tank known, and the temperature of the water known initially, it is easy to calculate the amount of power required to raise the water to boiling point (212°F.) within specific periods of time. In the illustration the generator output is led to the water tank by means of a transmission line terminating in a variable inductance for tuning the dummy load to resonance.

12. Other Applications.

It is clear from the fundamental principles underlying dielectric heating, and from the examples already quoted, that the method is potentially applicable over a very wide range of material. This section calls together examples in which the method has been tried, or is actually being used. Doubtless as time goes on many more materials will be brought within the scope of the process.

Experiments have been made with the dehydration of foods by means of high frequency heating. Foods examined included cabbage, carrot, wheat, onions and potatoes. Some 80% of the moisture was extracted by conventional methods; after which the vegetables were pressed into blocks under pressure of 500 lbs. per square inch, dehydration then being carried to 99% electronically. This was accomplished without burning or case-hardening the vegetables, and in one-tenth of the time required by other methods. It is stated that vegetables so treated will not deteriorate in one to two years in a hot humid climate. They can be reconstituted by soaking in water, when they assume their normal consistency, taste and aroma. The power required was 100 watts per lb. of food treated, the cost at commercial rates being $\frac{1}{2}$ d per lb. of water removed.

Dried whole-milk has also had its moisture content reduced from 2% to 1% by this method.

Dried food stuffs, such as flour, in any type of fibre package, can be sterilised by carrying the filled packages on a canvas conveyor belt between electrodes of a standard electronic heating unit. A heating period of 20 to 30 seconds is sufficient to destroy all stages of insect life, including eggs. This method of sterilisation has been applied to grain, milk and to killing pests in plant bulbs; and also to cooking and baking foods, roasting peanuts and several other applications. H.F. heat was early used in medical therapeutic treatment.

The sealing of glass joints in wireless bulbs by electrostatic heating has been patented, the claim being made that this eliminates risk of damage being done to bulb components by their exposure to the products of combustion, necessary when other methods are used.

It has also been used to heat glass in the manufacture of glass wool, in glueing safety glass, welding glass, heating footwear during manufacture, drying tobacco, wood, paper, textiles, powders, ceramics, skin footwear, leather, and for drying cork and artificial sponge. In the case of drying viscose sponge, this method of drying has been found especially useful, in that the uniformity of condition achieved prevents subsequent warping and the formation of cupped sponges, thus promoting the production of symmetrical sponges.

Low loss dielectrics do not heat up rapidly in the H.F. field. In fusing such materials by H.F. heat, it is suggested that they be first preheated by other means. Silicates may thus be preheated to 100° to 300°C., or organic dielectrics to 80°C.

13. Equipment.

The equipment used for generating the H.F. power is very similar to a radio transmitter, and a wide range of frequencies is available.

For practical purposes frequencies are usually within the range from 1 mc/s to 100 mc/s (300 to 3 metres), and frequencies of 10 to 20 mc/s (30 to 15 metres) are suitable for a wide variety of applications.

The frequency used should be as high as possible, say between 30 and 50 mc/s; but production of such equipment with reasonable efficiency and high power output is not easy. Most of the equipment at present available operates at a frequency of approximately 10 to 20 mc/s but, providing operation at this frequency does not limit dimensions in the load, it should be satisfactory. As mentioned previously, the upper frequency limit is set by dimensions of the material being treated, and also by valve design; and the lower frequency limit is fixed by the voltage without risk of breakdown from corona or arcing, since the voltage varies inversely with the square root of the frequency for a given ratio of heating.

Valves for frequencies above 10 mc/s are limited to about 50 kW.

The self-oscillator is the simplest form of generator, glass envelope valves being employed for up to a few hundred watts, silica valves for a range up to a few thousand watts, and external anode valves for powers above this.

Fig. 19 shows the basic oscillator circuit of a generator and Fig. 20 shows the series inductance method of coupling when the generator is close to the load, whilst Fig. 21 indicates the normal form of push-pull circuit generator encountered. In this it will be seen that the output is taken from a two-turn coupling coil, which is fed via condensers to a transmission line, the load itself being tuned to resonance by means of inductors in parallel. Equipment should be as simple, safe, and fool-proof as possible. It would appear that theoretical efficiency might be sacrificed to a con-

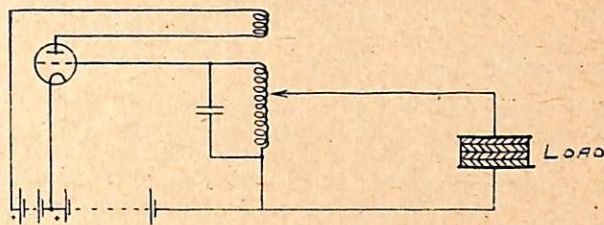


Fig. 19.—Basic Oscillator Circuit.

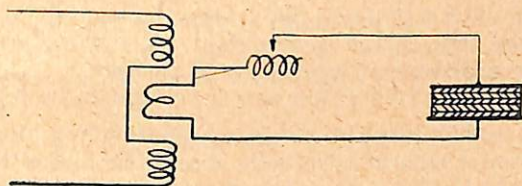


Fig. 20.—Series Inductance—can only be used when R.F. Generator is close to load.

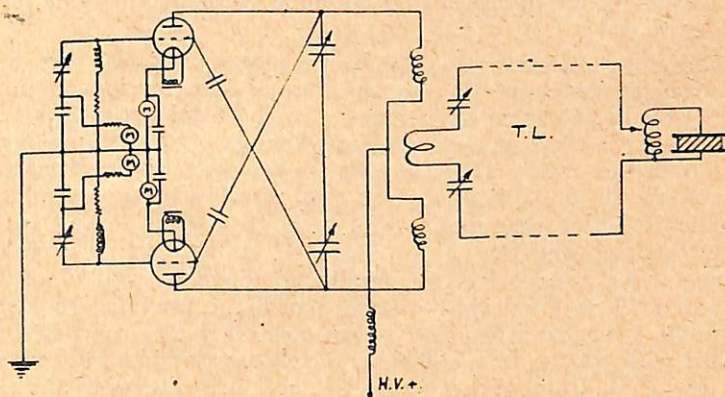


Fig. 21.—Output Coupling by means of 2-turn Pick-up Coil. Load tuned by Inductances in Parallel—use of T.L. between Generator and Load.

siderable extent to achieve simplicity of operation and general robustness. An automatic timing device is desirable, to ensure that the power is applied for the exact pre-set period which a heating operation may demand.

The optimum size of power of the equipment has not yet been established, and there are two schools of thought; one maintaining that fairly large units should be used serving a number of presses, and the other, that small units should be used serving one press only. It is probable that both systems will come into general use. The larger set will be more efficient electrically, the valves will probably have longer life, and it will be possible to have many refinements which would be uneconomical in the smaller set. An output of $2\frac{1}{3}$ kW. would probably be required, and considerable organisation would be necessary to permit operation of the equipment at maximum efficiency. With the use of small sets with an output of about 500 watts, the necessity for organisation does not arise to the same extent, since the H.F. equipment could be regarded as an accessory to the press. The valve depreciation of such small power sets may tend to be high.

Steps should be taken to minimise radiation from the equipment, to prevent interference with radio reception. For this purpose the equipment must be efficiently screened, and if reasonable care is taken in the design of the apparatus no undue amount of interference should occur.

It has been suggested that certain frequency bands should be allocated exclusively to H.F. heating equipment. No precautions against radiation would then be required, but it would be necessary for the frequency accuracy and stability of the equipment to be of a high order.

One firm makes a $2\frac{1}{2}$ kW. self-contained mobile unit only requiring direct connection to the normal low tension main of 200/240 volts, 50-cycle, single phase. The total mains input for an output of $2\frac{1}{2}$ kW. is approximately 7 kVA. Larger units could be supplied to order. Plug in coils are provided for frequencies of approximately 8, 12 and 22 mc/s and other frequencies could be supplied to order when required for such purposes as heating wood, asbestos, food, and the like. The H.T. supply can be varied in voltage over a wide range, permitting adequate control of the output down to low levels. Metal panels are provided to ensure adequate electrical screening; where necessary the iron parts are coated with copper, or non-ferrous panels are provided, to prevent heating of the framework by inductive action. Access to any part of the equipment operating at dangerous voltages can be obtained only after the main H.T. has been cut off, and the output terminals have been connected to earth. It is not possible to remove this earth so long as the enclosure door is open. The oscillator stage

is internally screened from the power area, and an automatic timing device will provide heating times between 20 seconds and 4 minutes, longer times being manually controlled.

The time of heating varies as the square of the thickness of the material for a given anode voltage, but is independent of the area.

A thickness of $1\frac{1}{4}$ " of phenolic material, with wood flour-filler in pellet form, can be heated in one minute, or in powder form in two minutes.

The electrodes are capable of taking pellets up to 3" thick. Blocks of material 6 lbs. weight can be heated in about 10 minutes, and the equipment can deal with weights up to 10 lbs.

Another firm manufactures a 350 watt unit with a range of frequencies from 25 to 45 mc/s for bakelite pellet heating, and also has in course of production a 3 kW. unit with operating frequencies of 5, 10 and 15 mc/s.

Other firms supply generators rated at $\frac{1}{4}$ kW. (30 mc/s), 1 kW. (30 mc/s), 2 kW. (18 mc/s) and 25 kW., with selected frequencies up to 20 mc/s; the latter has water-cooled valves and cold cathode mercury vapour rectifier.

Fig. 22 illustrates another generator having an output of approximately 11.5 kW. and a current consumption of approximately 30 kW. from the 1. t mains. It is provided with an oil-immersed motor-operated moving coil regulator, to ensure smooth variation of voltage from 50% to a maximum applied, the primary winding of the plate transformer enabling the D.C. output voltage of the rectifier to be followed smoothly through the same range. Cooling of valves and rectifier is by forced air circulation; the cool air is filtered on entry to the cubicles, filter packs being arranged for easy removal and cleaning. A D.C. generator is enclosed in one of the cubicles. This unit includes a 6 valve, 3 phase, full wave rectifier. Housed in an upper part are filament transformers; in the lower part of the cubicle, with stand-by valve in circuit, the protective devices are included together with a time-delayed relay to prevent the application of H.T. to the valves without the initial warming period.

The H.F. oscillator is enclosed in the second cubicle. The unit is complete with two silica enclosed repairable oscillator valves of the air-cooled type, the filaments of which are fed from filament transformers and hand-operated moving coil filter giving smooth operation of the voltage.

Tank and coupling coils and condensers are fully wired inside cubicle, the H.F. power being brought to two terminals. The load tuning unit is contained in a separate screened cubicle, the unit comprising a remote controlled motor operating variable inductors, the indicator on top showing the position of the inductors.

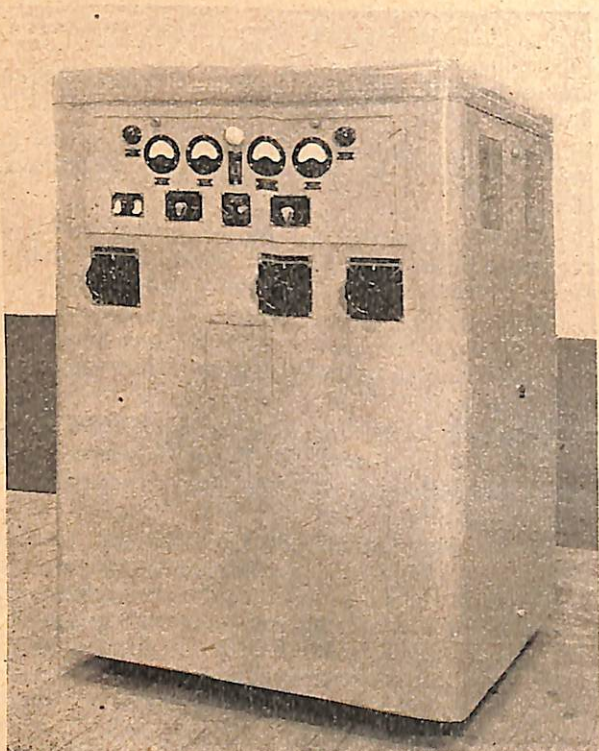


Fig. 22.—Ferranti-Wild-Barfield Dielectric Heating Equipment, Model 30 AD.

The following instruments are provided on the control panel at the front of the oscillating cubicle :—

- Oscillator valve filament meter.
- Grid current milliammeter.
- Anode current ammeter.
- Volt meter indicating H.T./D.C. output volts on rectifier.

The following controls are also provided :—

- Oscillator valve filament control.
- Output coupling control.
- Push buttons, switching main contactor.
- Push buttons, controlling moving coil regulator.
- Push buttons, controlling load tuning.

In addition, pilot lamps are provided to indicate :—

- (a) "Mains on."
- (b) "Relay closed."
- (c) "H.T. on."

Fuses for protective devices are included in the rectifier filament circuits, in the oscillator filament transformer circuits, and in the auxiliary circuits. A circuit breaker is also provided for the anode current circuit. A process timer is fitted to the front of the panel. The timer is electrically-driven, self re-setting, and adjustable by external knob from zero to 30 minutes.

Owing to the fact that certain rather unusual conditions and provisions must be made in order that the generator should have a universal application in wood-working and timber processing, it was decided that rather than attempt to modify any of the existing conventional R.F. generators, which were primarily adaptations of medical diathermy equipment working in the first case on pre-heating plastic pellets and powders, the problem should be considered on the basis of an entirely new design, expressly arranged for timber and wood heating or processing. A generator was therefore designed, as illustrated in Fig. 23, on the basis of the following specification :—

The frequency is 10 mc/s, with provision for change of frequency by means of coil changing, if required.

Variable coupling of output provides the widest possible range of capacities that can be obtained. The range 0-250 mmfd. is variable whilst the extension from 250-2500 or 3000 mmfd. is made by means of suitable coil tapping. This ensures that 250 mmfd. is variable even under this extended condition of coupling.

Positive output indication is by means of a single meter calibrated directly in kilowatts. This meter is in the circuit of the oscillator valve so that the cathode earth current passes directly through the meter. The method, therefore, indicates any rise in output power due to conditions within the "work" electrodes varying. The cathode earth circuit is passed through an overload coil in the contactor so that at any pre-set figure excessive cathode current causes the contactor to trip, thus switching off the H.F. power.

Simplicity of controls and push button operation for production purposes with provision for remote control when required. The tuning control takes the form of a single knob on the side of the panel. Stability of tuning when under working conditions is essential.

Output is unbalanced with respect to earth, but provision is made for this to be balanced when necessary for certain purposes. This is incorporated in the design and results in a cleaner job than having to modify a set at a later date.

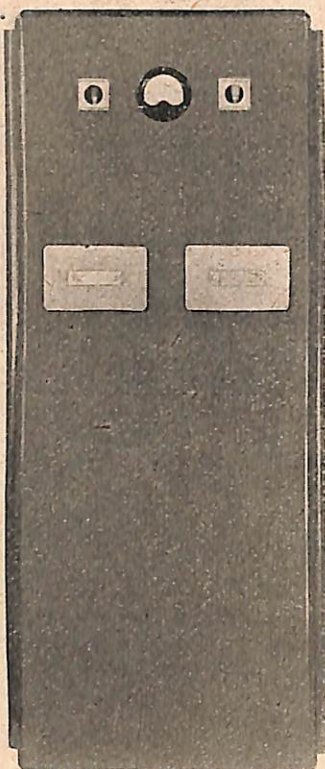


Fig. 23.—Pye 3 kw. Dielectric Heating Generator. Designed for Wood Applications.

Easy access for maintenance and/or repair purposes with micro switches fitted to removable panels.

Complete air filtration in view of the extremely dusty atmosphere in the workshops. A micro switch is provided between the filter so that it is impossible to operate the set with the filter removed.

Output power $2\frac{1}{2}$ kW. continuous rating, with provision for intermittent peak working up to $3\frac{1}{4}$ kW.

Power supply is 415 volts, 50 cycle, 3 phase.

The main switch is provided at the side of the generator, with fuses behind a removable plate placed at some convenient point.

The front of the generator which faces the operator has the output indicating meter ; a green lamp indicating that mains power has been switched on, and also that the valve filament is alight ; a red lamp to indicate when H.F. power is switched on, and two connecting bars at approximately 3" above bench level.

BIBLIOGRAPHY.

- A. W. ALLWOOD, "Electric Heating in Plywood Manufacture." *Discovery*, 1944, 5, 183-4.
- BAKELITE CORPN., "Heatronic Moulding." *Plastics World*, 1943, I., No. 2, 1; *Brit. Plastics*, 1943, 15, 305.
- J. W. BAYLISS, "Industrial Radio-Frequency Heating." *Electrician*, 1944, 132, 360.
- R. A. BIERWORTH & C. N. HOYLER, "Radio Frequency Heating Applied to Wood Glueing." *Proc. I.R.E.*, 1943, 31, 529-37; *Sci. Abs.*, 1944, 47B, 37.
- N. R. BLIGH, "Industrial Applications of Radio-Frequency Methods of Heating." *Electrician*, 1944, 132, 96; *Elec. Rev.* 1944, 134, 163; *Elec. Times*, 1944, 105, 143.
- BRITISH PLASTICS FEDERATION, PLASTICS COMMITTEE—
"Electronic Heating," Post-War Building Studies, No. 3. *Plastics*, 1944, p. 34.
- G. H. BROWN, "Heat Conduction Problems in Presses used for Glueing Wood." *Proc. I.R.E.*, 1943, 31, 537-48.
- G. H. BROWN, "Electrostatic Heat for Resin Bonding." *Modern Plywood*, 1943, Nov. 3, 182-6.
- G. H. BROWN, "High Frequency Heating for Plastics." *British Plastics*, 1943, 15, 322-6.
- D. W. BROWN, "High Frequency Heating." *Plastics*, 1944, 8, 218-26.
- G. H. BROWN, "Sheet Plastics Sealed by Radio Current." *Plastics*, 1943, 7, 349.
- G. H. BROWN, "Radio Frequency Heating." *Chem. Age*, 1944, 50, 364.
- L. J. C. CONNELL, "Application of Radiant and Inductive Heating to Industrial Processes." *G.E.C. Journal*, 1944, 13, No. 1, 10-32.
- K. C. DE WALT, "Study of High-Frequency Heating." *Electronics*, 1932, Nov., p. 338. Tiemann, "Wood Technology," 1942, p. 202.
- G. DRING, "Radio Heating." *Wireless World*, 1944, 50; Feb., 41-2.
- G. DRING, "Radio-Frequency Heating." *Elec. Times*, 1944, 105, 143; *Elec. Review*, 1944, 134, 163; *Electrician*, 1944, 132, 96; *Elec. Ind.*, 1944, 44, 100-1.
- J. F. DRIVER, "Electrostatic Heating." *Machinery Lloyd*, 1943, 15, No. 23, 37-9.
- R. A. DUFOUR & H. A. LEDUC, "Processes and Arrangements for Heat Treatment of Rubber or Similar Materials." B.P. 472671.
- R. A. DUFOUR & H. A. LEDUC, "Apparatus for Heating Liquids, particularly Latex." *Ital. P.* 357222; *Chimica e Ind.*, 1938, 20, lxix.
- L. M. DURYEE, "Radio Frequency Speeds Heating of Moulded Plastics." *Elec. World* 1944, 121, March 4110.
- A. V. ERMOLAEV & I. S. OKRIMENKO, "Use of Extremely High Frequency in the Rubber Industry." *Kauchuk i Rezina*, 1940, No. 9, 33-6; *Chem. Abs.*, 1941, 35, 929.
- C. V. FIELDS, "Electronic Heating Design Chart." *Electronics*, 1944, 17, April, 102-7.
- H. C. GILLESPIE, "Radio Heat Proving Its Usefulness in Many Ways." *Abstract: Sci. American*, 1944, 170, 29.
- J. F. GILLIES, "Developments in Insulating Materials," *J.I.E.E.*, 1940, 86, 66-70.
- GIRDLER CORPN., "High-Frequency Electrostatic Heating: Its Possible Industrial Uses," *Elec. News*, 1942, 51, No. 22, 38-40.

- W. GODFREY & P. H. BILHUBER, "High-Frequency Glueing of Resins." *Mod. Plastics*, 1943, Sept., 89-93.
- T. E. GOLDUP, Institution of Electrical Engineers, Wireless Section. Chairman's Address, *J.I.E.E.*, 1944, 91; 1. 39-48.
- E. M. GUYER, "High-Frequency Electric Glass Welding." *Trans. Electro Chem. Soc. Am.*, 1941, 79, 187-198; Zade: *Plastics*, 1944, 8, 100-9.
- E. M. GUYER, "High-Frequency Heat Used to Make Plywood." *Elec. World*, 1942, 117, June 27, 70-2.
- L. HARTSHORN, "Principles of High-Frequency Heating." *Abstract, Cham. and Ind.*, 1944, 185-6; *Nature*, 1944, 153, 641-2.
- H. HERNE, "Thermal Conduction with Radio Heating." *Wireless Eng.*, 1944, 21, 377-82.
- C. N. HOYLER, "Electronic Sewing Machine." *Electronics*, 1943, 16, No. 8, 9P-3, 160, 162, 164, 166, 168; *Sci. Abs.*, 1943, 46B, 257.
- C. N. HOYLER, "Dielectric Heating, a Potential Method for the Chemical Industry." *Chem. Age*, 1943, 49, 210-12.
- C. N. HOYLER, "Cycleweld—a new Bonding Process." *Mod. Plastics*, 1943, Sept., 65-9.
- W. J. JARRARD, M. R. MORITZ and H. P. ZADE—
"Consolidation of Joining Surfaces of Organic Thermo-Plastic Material." *B.P.* 555054.
- J. P. JORDAN, "Theory and Practice of Industrial Electronic Heating." *Gen. Elec. Review*, 1943, 46, 675-83.
- J. P. JORDAN, "Application of Vacuum-Tube Oscillators to Inductive and Dielectric Heating in Industry." *Elec. Eng.*, 1942, 61, 831-4.
- J. P. JORDAN, "Radio-Frequency Heating Speeds Plywood Bonding." *Electronics*, 1942, 15, No. 11, 79.
- J. P. JORDAN, "Possible Industrial Uses of High-Frequency Electrostatic Heating." *Elec. News and Eng.*, 1942, 151, Nov. 15, 38-40.
- J. P. JORDAN, "Electronic Power Sources for Industrial Heating." *Electronic Ind.*, 1942, Nov., 56.
- K. KRAMMER, "Heat Treatment of Materials with the Aid of High Frequency Field." *G.P.* 709448; *Chem. Abs.*, 1943, 37, 3636.
- L. L. LANGTON, "Radio Heating." *Wireless World*, 1944, 50, March, 70-2.
- L. L. LANGTON, "Radio-Heating Equipment," I., II., III., IV. *Wireless World*, 1944, 50, 111-14, 137-9, 179-82, 212-13.
- I. F. LAUCK'S CO., "Spot Welding with Glue." *Brit. Plastics*, 1943, 15, No. 169, 29. Zade: *Plastics*, 1944, 8, 100-9.
- A. W. LAY, "Application of High Frequency Currents in Medicine and Surgery." *Marconi Review*, 1934, 51, 14-29; 52, 1-15. Zade: *Plastics*, 1944, 8, 100-9.
- K. S. LION, "Dosimetry and Local Distribution of Energy in the Electric High-Frequency Field." *J. Appl. Phys.*, 1943, 14, 545-51.
- A. D. LITTLE, Inc., "High-Frequency Heating of Non-Metallic Materials." *Ind. Bull.*, 1943; *Engineer*, 1943, 176, 134.
- C. J. MADSEN, "High-Frequency Heating." *Abstract: J. Appl. Phys.* 1944, 15, No. 2, XII.
- P. I. MEDUEDCHUCK, "Action of an Electric Field of Ultrasonic Frequency on Some Organic Compounds." *Trudy Rostov Med. Inst.*, 1940, No. 7, 454-7; *Khim. Ref. Zhur.*, 1941, 4, No. 5, 22-3; *Chem. Abs.*, 1943, 37, 5658.

- E. MITTELMAN & D. KOBAK, "Dosage Measurement in Short-Wave Diathermy," *Arch. Phys. Therpy*, 1938, Dec., 19, 725-36, 763-5; Zade: *Plastics*, 1944, 8, 100-9.
- E. MITTELMAN, "Design Chart for Radio-Frequency Heat Treatment Generators," *Electronics*, 1941, Sept., 1943, June, 200.
- G. C. NONKEN, "Electronic Heating Device: Industrial Application," *Paper Trade J.*, 1944, 118; *Tappi*, 59-61; *J. Text Inst.*, 1944, 35, 262A.
- RADIO CORPN. OF AMERICA, "Glueing Wood with Radio Waves," *Electronics*, 1943, Nov., 163, advt.
- C. S. RICKER, "Cold Heat to Expedite Plywood Fabrication," *Aviation*, 1943, 42, No. 3, 116-20, 327, 329.
- C. A. SCARLOTT, "Induction and Dielectric Heating: Types and Applications of High-Frequency Generators," *Elec. News and Eng.*, 1944, 53, May, 1, 55-7.
- V. W. SHERMAN, "Thin Case-Hardening with Radio-Frequency Energy," *Aero. Eng. Rev.*, 1943, 2, No. 5, 7, 9, 11, 13, 15-16, 101; *I.A.E. Auto Res. Comm. Abs.*, 1943, Nov. 1551.
- V. W. SHERMAN, "Dehydration of Food by Radio-Frequency Energy," *Elec. Comm.*, 1943, 21, 125-6; *Nature*, 1943, 152, 260-1.
- V. W. SHERMAN, "Electronic Dehydration of Foods," *Electronics*, Feb., 94-7.
- V. W. SHERMAN, "Electronic Sterilization in the Package," *Modern Packaging*, 1944, 17, No. 6, 99.
- V. W. SHERMAN, "Radio-Frequency Heating of Aircraft Spars and Gas Tanks," *Electronics*, 1944, 17, Feb., 150, 152, 154.
- V. W. SHERMAN, "High Density Through High Frequency," *Mod. Plastics*, 1944, March, 34-5.
- L. G. STEPHEN & H. J. HOLMQUIST, "Drying Lumber with High-Frequency Electrical Fields," *Wood Products*, 1936, Oct. and Nov.; Tiemann: "Wood Technology," 1942, p. 202.
- J. P. TAYLOR, "Dielectric and Induction Methods of Creating Heat," *Elec. News and Eng.*, 1943, 52, Dec. 1, 50-2.
- H. D. TIEMANN, "High-Frequency Electrical Methods for Drying and Glueing Wood," *Wood Technology*, New York; Pitman, 1942, pp. 193-202.
- T. C. VAUGHAN (et al), "Drying of Ceramics Products by Use of Induced High-Frequency Electrical Energy," *Virginia Polytechnic Institute, Engineering Expt. Station Series, Bull.* No. 42, 1940, Jan.; Tiemann: *Wood Technology*, 1942, p. 202.
- WINGFOOT CORPN., "Improvement in and Relating to Heat-Sealing Rubber Hydrochloride Surfaces," B.P. 559111.
- W. M. WITTY, "High-Frequency Heating in Plywood Manufacture," *Aero. Research, Ltd., Bull.* No. 6, 1943, June.
- W. M. WITTY, "High-Frequency Heating of Non-Metallic Materials," *Engineer*, 1943, 176, 134.
- ANON., "Applications of Vacuum Tube Oscillators to Inductive and Dielectric Heating in Industry," *Electrical Eng.*, U.S.A., 1942, 61, No. 11, 831; Zade: *Plastics*, 1944, 8, 100-9.
- ANON., "Radio Oven Cooks Penicillin," *Daily Mail*, 1944, June 28.

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